BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B70 09084

SUBJECT: Preliminary Evaluation of SM/RCS Capability to Abort to Earth Entry from the Relaxed Free Return Profile - Case 310

DATE: September 30, 1970

FROM: R. J. Stern

ABSTRACT

The minimum ΔV required to provide for safe earth entry to an unspecified landing area from relaxed free return trajectory profiles is determined. The cases considered are feasible J-type missions to Copernicus, Marius Hills and Hadley during the time frame 8/71 - 10/71. Results are presented for both nominal and 3σ dispersed TLI.

Using a preliminary estimate for SM/RCS ΔV available, it was found that for the worst nominal case observed, the SM/RCS has the capability to perform the abort maneuver up to 35 hours after TLI in the normal CSM + LM configuration. In the event of CSM separation failure from the S-IVB, SM/RCS aborts would be possible up to 16.5 hours after TLI for this same case.

For the same worst case and a 3σ dispersed TLI, the SM/RCS provides abort capability up to 8 hours after TLI for the CSM + LM configuration. With the S-IVB attached the SM/RCS alone can provide the abort capability for only 2.5 hours after TLI. However, by using the SM/RCS in conjunction with ΔV sources from S-IVB systems, abort capability can be provided up to 10 hours.

The effect of launch azimuth variations on abort ΔV required is shown to be relatively small.

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MEMORANDUM FOR FILE

Introduction

For the relaxed free return trajectory profile, the spacecraft is injected directly into a 60 nautical mile perilune altitude non-free-return translunar trajectory. All such trajectories are designed to satisfy a DPS abort constraint, i.e. in the event of complete Service Propulsion System (SPS) failure at lunar orbit insertion, the Lunar Module Descent Propulsion (DPS) has the capability to return the spacecraft to a safe earth entry. Failure of the CSM to separate from the S-IVB for transposition and docking could result in a time-critical abort maneuver, since the SM/RCS must provide the abort ΔV. Therefore, it is desirable to determine the ΔV requirements placing the spacecraft on a free return trajectory relatively soon after translunar injection (TLI).

The minimum abort ΔV required to provide a safe entry (unspecified landing area) from various points along the nominal non-free return trajectory was determined for sample trajectories to possible sites for the first J mission, Marius Hills, Hadley and Copernicus. An estimate of the 3σ abort ΔV requirements for a dispersed TLI is also presented. All nominal trajectories satisfy a DPS abort constraint, have sun elevation angles (SEA) at lunar landing between 5-14 degrees and were targeted using a 66-hour lunar surface staytime and 36 revolutions in orbit between LM ascent and transearth injection.

Estimate of Abort ΔV Available

The translational ΔV available for the abort maneuver was estimated for two spacecraft configurations. The first configuration, or mode, consists of the CSM and LM after normal transposition, docking, and separation from the S-IVB. In this mode the ΔV available from the SM/RCS is estimated. For the second mode it is assumed that CSM separation from the S-IVB is not possible and the configuration consists of the S-IVB, CSM and LM. For this mode the available SM/RCS ΔV is also estimated. Additional ΔV capability is available in this configuration from several S-IVB systems up to 10 hours* after TLI (Reference 1). Weights for the Mode I and II configurations were taken at 103,000 and 145,000 lbs respectively.

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*Lifetime of S-IVB batteries.

The maximum SM/RCS ΔV was estimated assuming 1220 lbs of usable propellant (Reference 2). This was converted into translational ΔV capability using conversion factors of 11.7 lbs/fps (Mode I) and 16.6 lbs/fps (Mode II). These factors were extrapolated from the data of Reference 3 for PGNCS four jet + x (aft-firing) translations. The results are presented in Table I. From the maximum value, allotments were made for attitude control and midcourse corrections. An estimate of the SM/RCS propellant required for attitude control in the Mode I configuration was made using the data of Reference 2. This estimate included allotments for transposition, docking, LM ejection, passive thermal control (PTC) and attitude maneuvers for the abort maneuver, four midcourse corrections, and orientation to separation attitude prior to entry. For the second mode, SM/RCS propellant requirements for transposition, docking and LM ejection were excluded and propellant requirements for other attitude maneuvers were scaled in accordance with the differing moments of inertia for the two configurations. Moment of inertia data was obtained from References 4 and 5. For the higher moments of inertia of the Mode II configuration, the required attitude changes at the same rate used for Mode I (.2 deg/sec) would result in a high SM/RCS propellant consumption. Therefore for Mode II the attitude maneuver rate for all attitude changes* except that required for the abort maneuver was assumed to be .05 deg/sec.** Additional SM/RCS propellant savings might also be available through the use of single jet firing, since one jet will be more effective in accelerating the spacecraft configuration about the pitch and yaw directions than another. The reasons are that the position of the C.G. along the roll (x) axis is not at the SM/RCS location and that the SM/RCS jets are inclined at approximately 10 degrees to the x-axis. Subtracting the allotment for attitude control and 15 ft/sec for midcourse corrections resulted in a SM/RCS ΔV abort capability of 76.7 ft/sec for Mode I and 49.1 ft/sec for Mode II. The allotments for attitude control presented here are preliminary estimates; actual requirements should be determined from a mission specific consummables study.

It should be noted at this point that continuous engine burn duration for SM/RCS aft-firing engines should not exceed 750 seconds on any one engine (Reference 3, paragraph 3.3.1.4). Violation of this constraint causes damage to service module insulation and results in service module SPS and RCS tank temperature increases. At an average propellant flowrate of

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*The roll rate of .3 deg/sec in PTC was maintained.

**Discrete maneuver rates of .05, .2, .5, and 2.0 degrees per second may be selected through the DSKY using the PGNCS.

1.3 lbs/sec for PGNCS four jet + x translations (Reference 3), this constraint indicated that not more than 975.0 lbs of propellant or 80% of the usable propellant should be consumed for a single continuous burn. This percentage is not exceeded by the SM/RCS abort ΔV allotments in Table I.

Results for Nominal TLI

Results for a nominal TLI are illustrated in Figures 1-6 where the minimum abort ΔV is presented as a function of time from TLI. Also presented in Figures 1-6 is the estimated SM/RCS ΔV available for the abort maneuver. Times from two to thirty hours were considered. Figures 1-3 contain the abort ΔV required from nominal trajectories which were SPS fuel optimized with respect to translunar trajectory energy within the limits imposed by the 5-14 degrees sun elevation constraint. The highest abort ΔV occurs for a mission to Copernicus (8/27/71) as a result of the long translunar flight time for that trajectory.

The effect of launch azimuth variations on abort ΔV is illustrated in Figure 4-6 for sample missions to Copernicus (8/27/71), Marius Hills (8/29/71), and Hadley (8/24/71). For Figures 4-6 the sun elevation at landing was constrained at 10 degrees and the launch azimuth varied from 72-96 degrees. The variations in launch azimuth have relatively small effect on abort ΔV due to the small variations in trajectory energy and translunar flight time. The effect of larger variations in translunar flight times may be seen from a comparison of the abort ΔV for the Copernicus mission launched on 8/27/71 with launch azimuth = 72° and SEA = 14° (Figure 1) with the abort ΔV for the same mission with SEA = 10° (Figure 4). The translunar flight times for these cases are 89.9 and 82.4 hours respectively.

Results for Dispersed TLI

The abort ΔV required in the presence of TLI dispersions is presented in Figures 7-9 for the SPS optimized August mission opportunities. Three-sigma (3σ) dispersions are approximated by a ±10 ft/sec variation in TLI velocity (Reference 6). These results indicate that for the worst case (Copernicus) the SM/RCS can provide 3σ abort capability up to eight hours after TLI for the CSM + LM configuration. With the S-IVB attached the SM/RCS alone could provide 3σ abort capability for only 2.5 hours after TLI. However, with the use of the S-IVB ΔV sources, 3σ capability is available up to ten hours after TLI.

Summary

Using preliminary estimates for SM/RCS propellant available for an abort maneuver the capability of aborting from the relaxed free return profile for sample missions to Copernicus, Marius Hills and Hadley was investigated for the time period 8/71 - 10/71. For the highest observed abort ΔV case it was shown that three-sigma abort capability is available up to eight hours after TLI in the normal CSM + LM configuration. In the event of S-IVB separation failure three-sigma abort capability is available up to ten hours after TLI by utilizing S-IVB ΔV sources in addition to the SM/RCS. The effect of launch azimuth on abort ΔV is relatively small.

R. J. Stern

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Attachments

TABLE I

ABORT ΔV AVAILABLE (ft/sec)

	MODE I (CSM + LM)	MODE II (CSM + LM + S-IVB)
Maximum SM/RCS ΔV	104.2 ft/sec (1220)*	73.2 ft/sec (1220)
ΔV Available from S-IVB Systems up to 10 hrs. post TLI. (LOX DUMP, APS, LH2 VENT)	----	46.0 ft/sec
Allotment for Attitude Control	12.5 ft/sec (146)	9.1 ft/sec (151)
Allotment for Midcourse Corrections	15.0 ft/sec	15.0 ft/sec
ΔV Available for Abort	76.7 ft/sec	95.1 ft/sec including S-IVB Systems 49.1 ft/sec SM/RCS only

*Numbers in parenthesis denote pounds of SM/RCS propellant.

REFERENCES

1. MSC Memorandum 70-FM54-136, Free Return Flyby Capability From A Relaxed Free-Return (DPS Returnable) Translunar Profile for the Case of No CSM Separation from the S-IVB, D. S. Scheffman, May 25, 1970.

2. Preliminary Consumables Analysis for the Apollo J-Type Missions, MSC Internal Note 69-FM-316, December 24, 1969.

3. CSM/LM Operational Data Book, Volume I, CSM Data Book, Part I, Constraints and Performance, NASA SNA-8-D-027(I), April 15, 1970, Revision 3.

4. CSM/LM Spacecraft Operational Data Book, Volume III, Mass Properties, NASA SNA-8-D-027(III), August 20, 1969, Revision 2. (Mission H3, CSM 110/LM-8).

5. Saturn V/AS-509 Final Predicted Operational Mass Characteristics, Depletion Cutoff (Apollo 14 Mission) S&E-ASTN-SAE-70-26, March 31, 1970.

6. MSC Memorandum 70-FM54-189, Return-to-Earth ΔV Required for Three Relaxed Free-Return Trajectories, G. L. Norbraten, August 5, 1970.

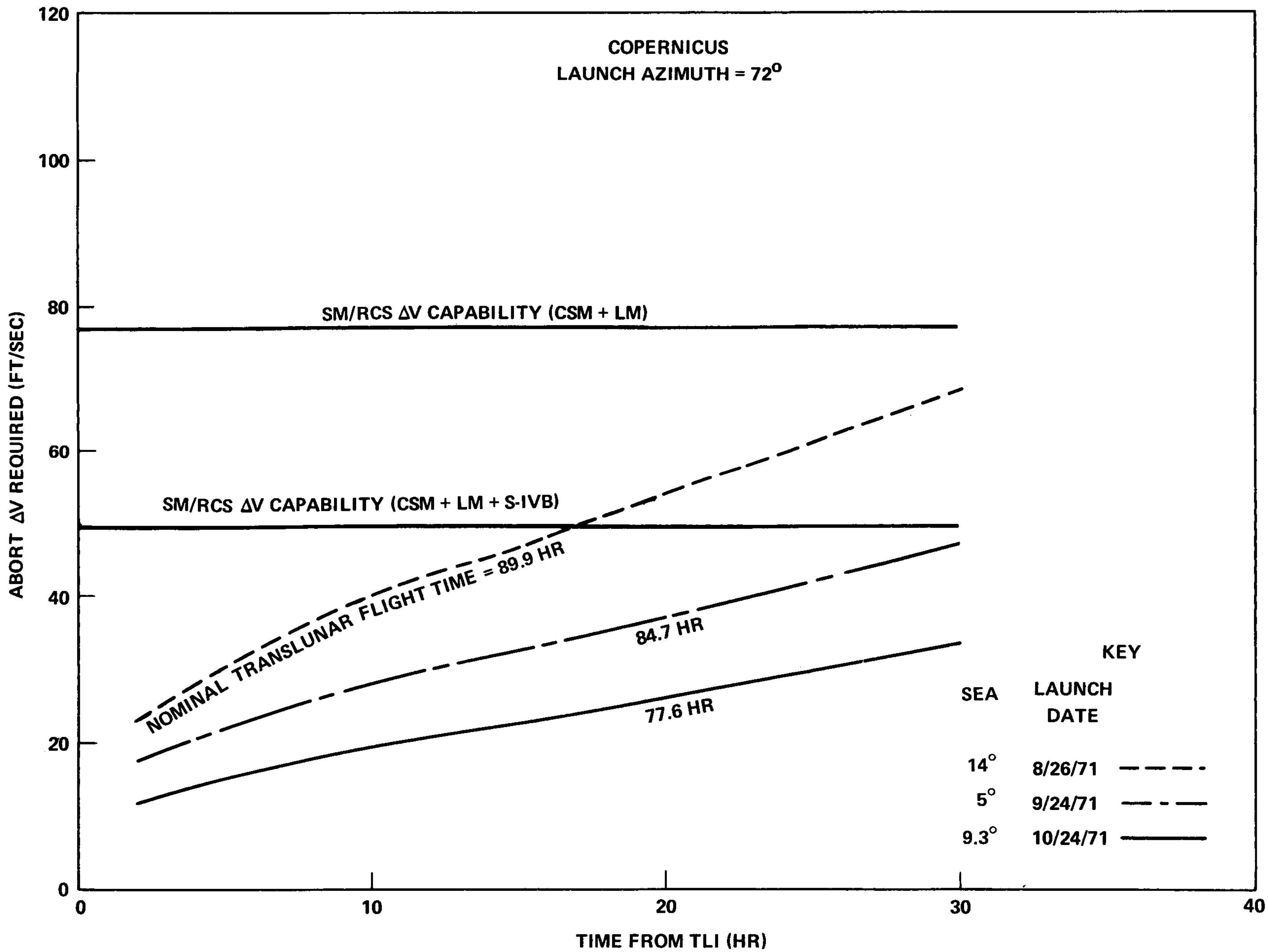


FIGURE 1 - ABORT ΔV REQUIRED TO ACHIEVE FREE RETURN FROM RELAXED FREE-RETURN TRAJECTORY vs TIME FROM TLI. (OPTIMIZED MISSIONS TO COPERNICUS 8, 9, 10/71)

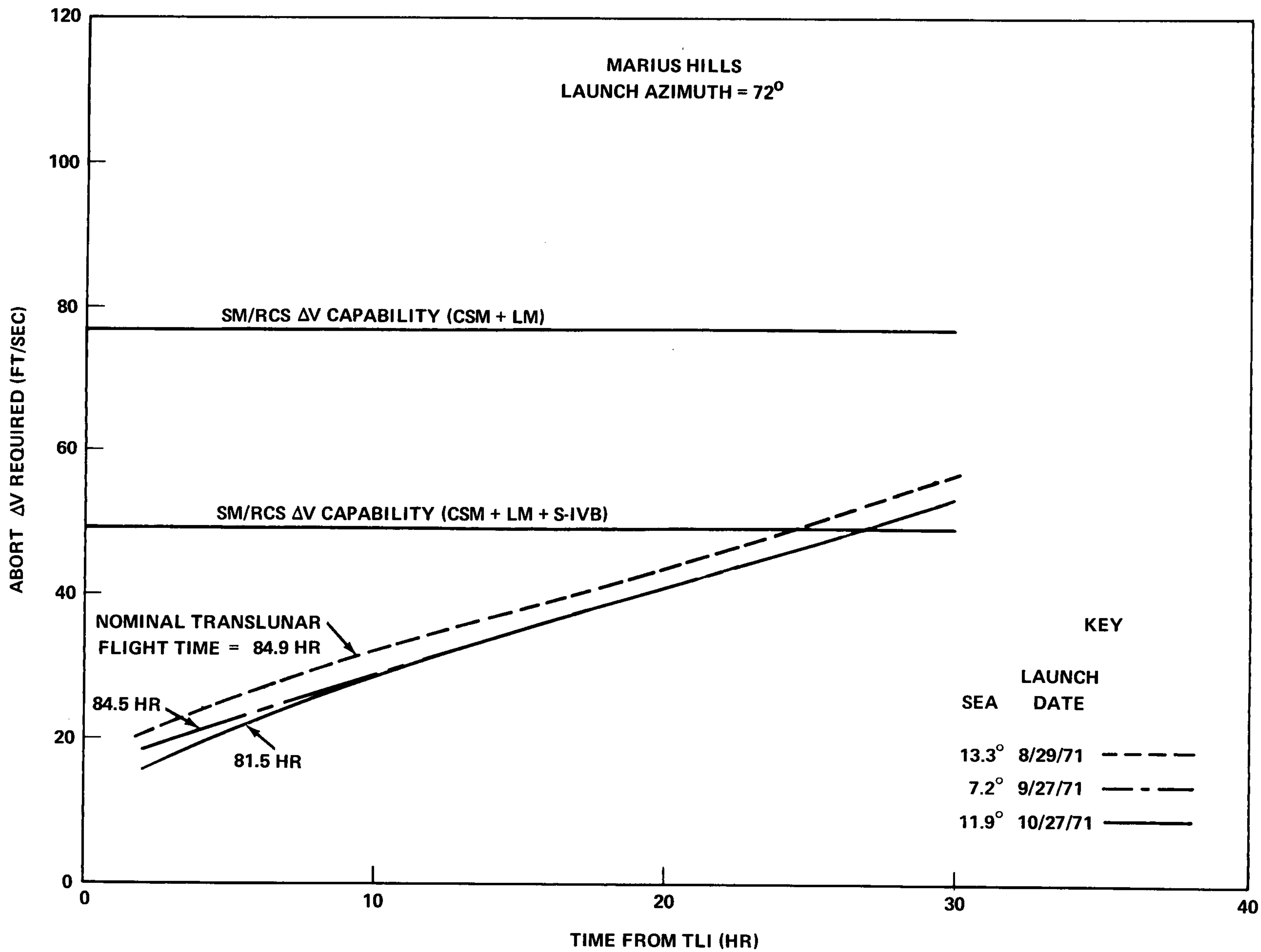


FIGURE 2 - ABORT ΔV REQUIRED TO ACHIEVE FREE RETURN FROM RELAXED FREE RETURN TRAJECTORY vs TIME FROM TLI. (OPTIMIZED MISSIONS TO MARIUS HILLS 8, 9, 10/71)

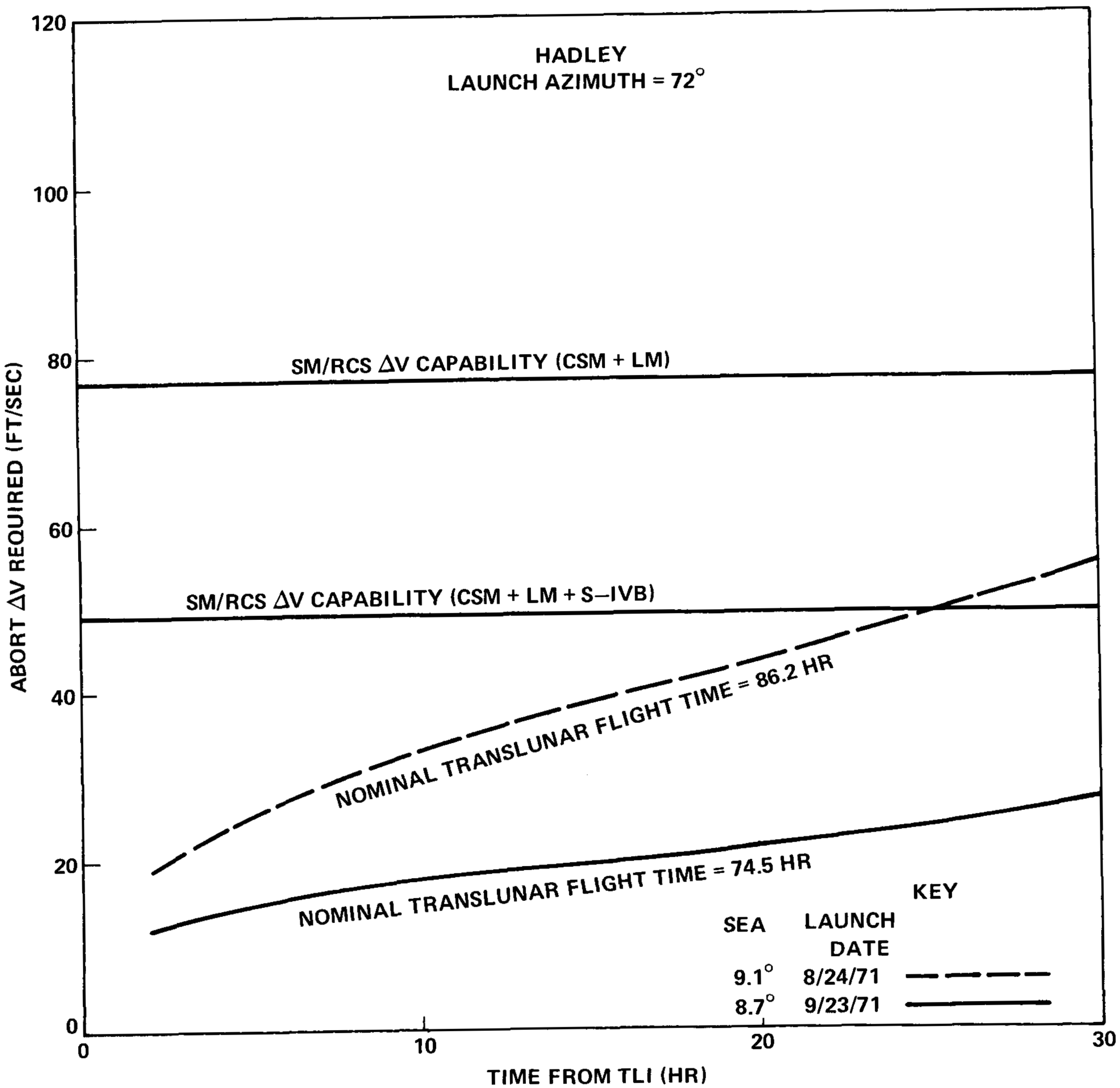
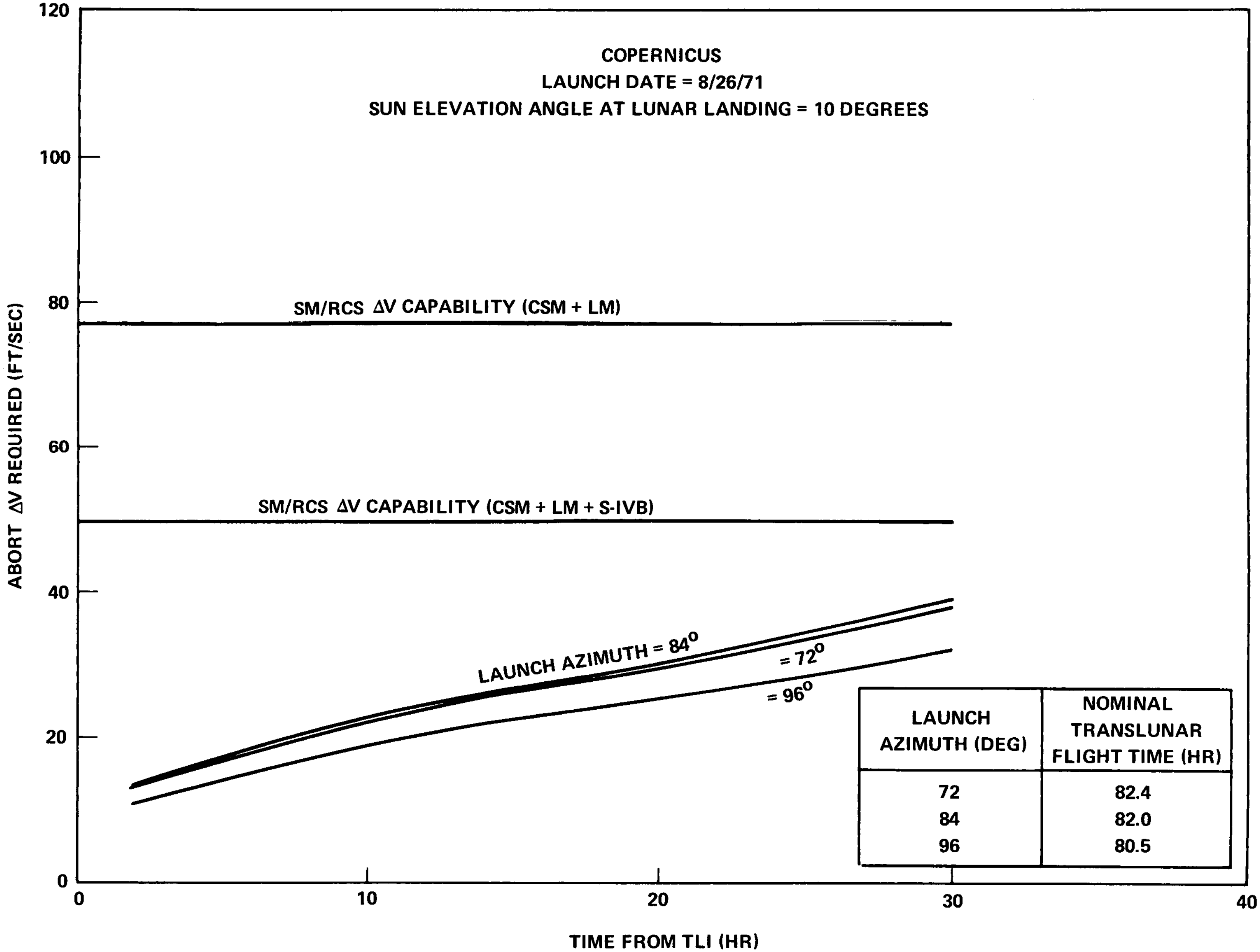
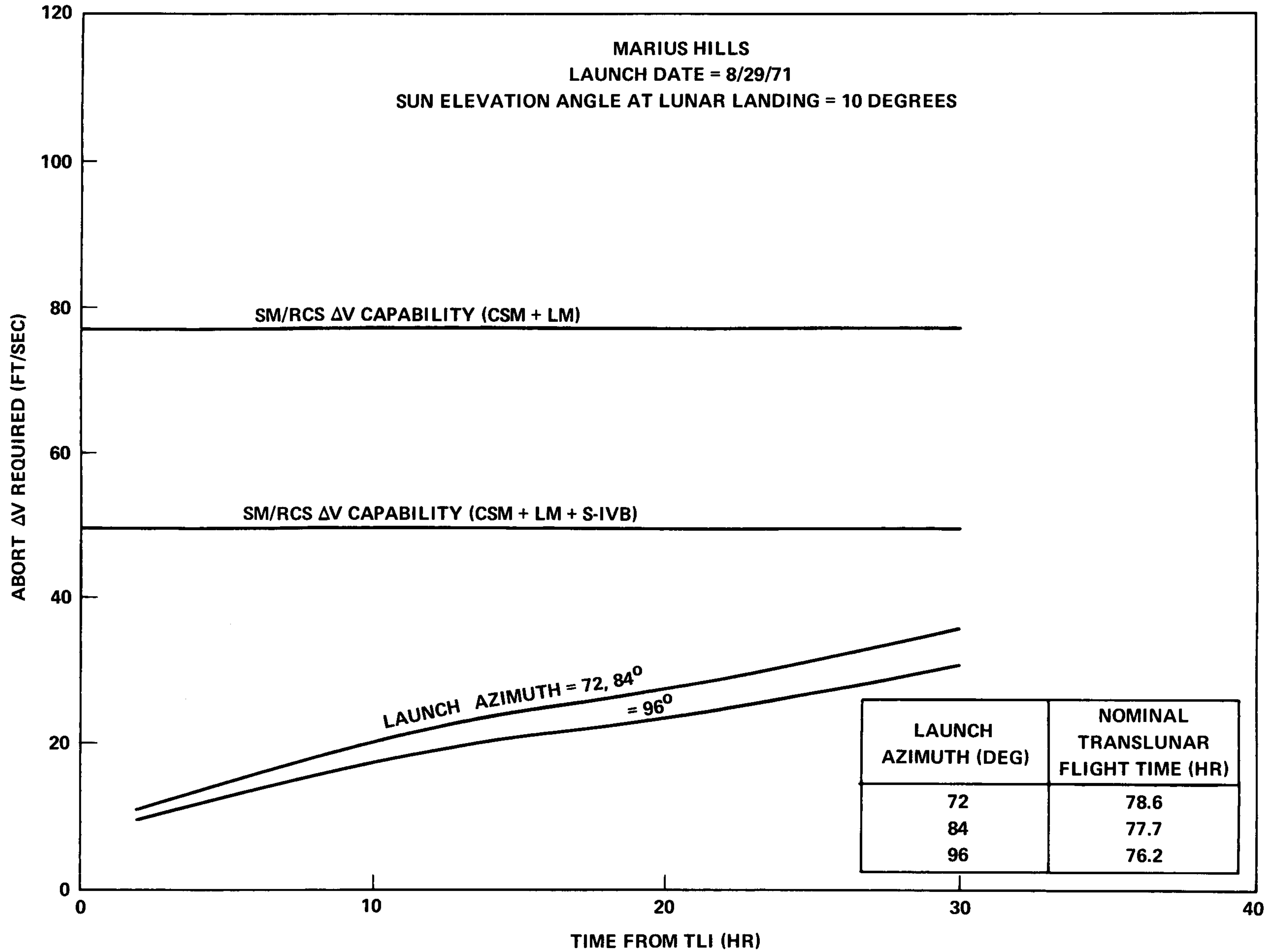


FIGURE 3 - ABORT ΔV REQUIRED TO ACHIEVE FREE RETURN FROM RELAXED FREE RETURN TRAJECTORY VS. TIME FROM TLI. (OPTIMIZED MISSION TO HADLEY 8, 9/71)



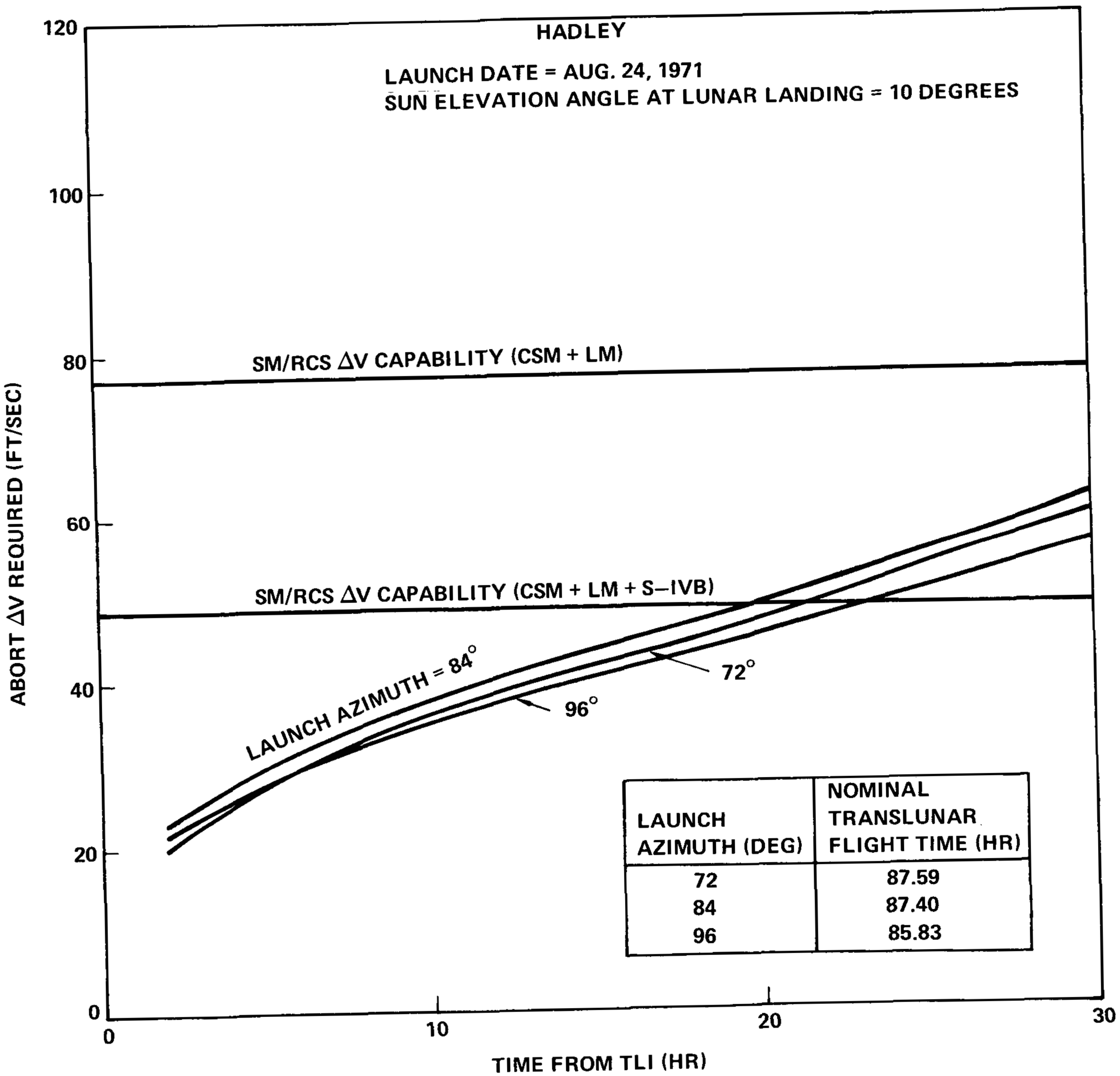
LAUNCH AZIMUTH (DEG)	NOMINAL TRANSLUNAR FLIGHT TIME (HR)
72	82.4
84	82.0
96	80.5

FIGURE 4 - ABORT ΔV REQUIRED TO ACHIEVE FREE RETURN FROM RELAXED FREE RETURN TRAJECTORY vs TIME FROM TLI (LAUNCH AZIMUTH VARIATIONS, COPERNICUS, 8/71, SEA = 10°)



LAUNCH AZIMUTH (DEG)	NOMINAL TRANSLUNAR FLIGHT TIME (HR)
72	78.6
84	77.7
96	76.2

FIGURE 5 - ABORT ΔV REQUIRED TO ACHIEVE FREE RETURN FROM RELAXED FREE RETURN TRAJECTORY vs TIME FROM TLI. (LAUNCH AZIMUTH VARIATIONS, MARIUS HILLS, 8/71, SEA = 10^{o})



LAUNCH AZIMUTH (DEG)	NOMINAL TRANSLUNAR FLIGHT TIME (HR)
72	87.59
84	87.40
96	85.83

FIGURE 6 - ABORT ΔV REQUIRED TO ACHIEVE FREE RETURN FROM RELAXED FREE RETURN TRAJECTORY VS. TIME FROM TLI. (LAUNCH AZIMUTH VARIATIONS HADLEY, 8/71, SEA = 10°)

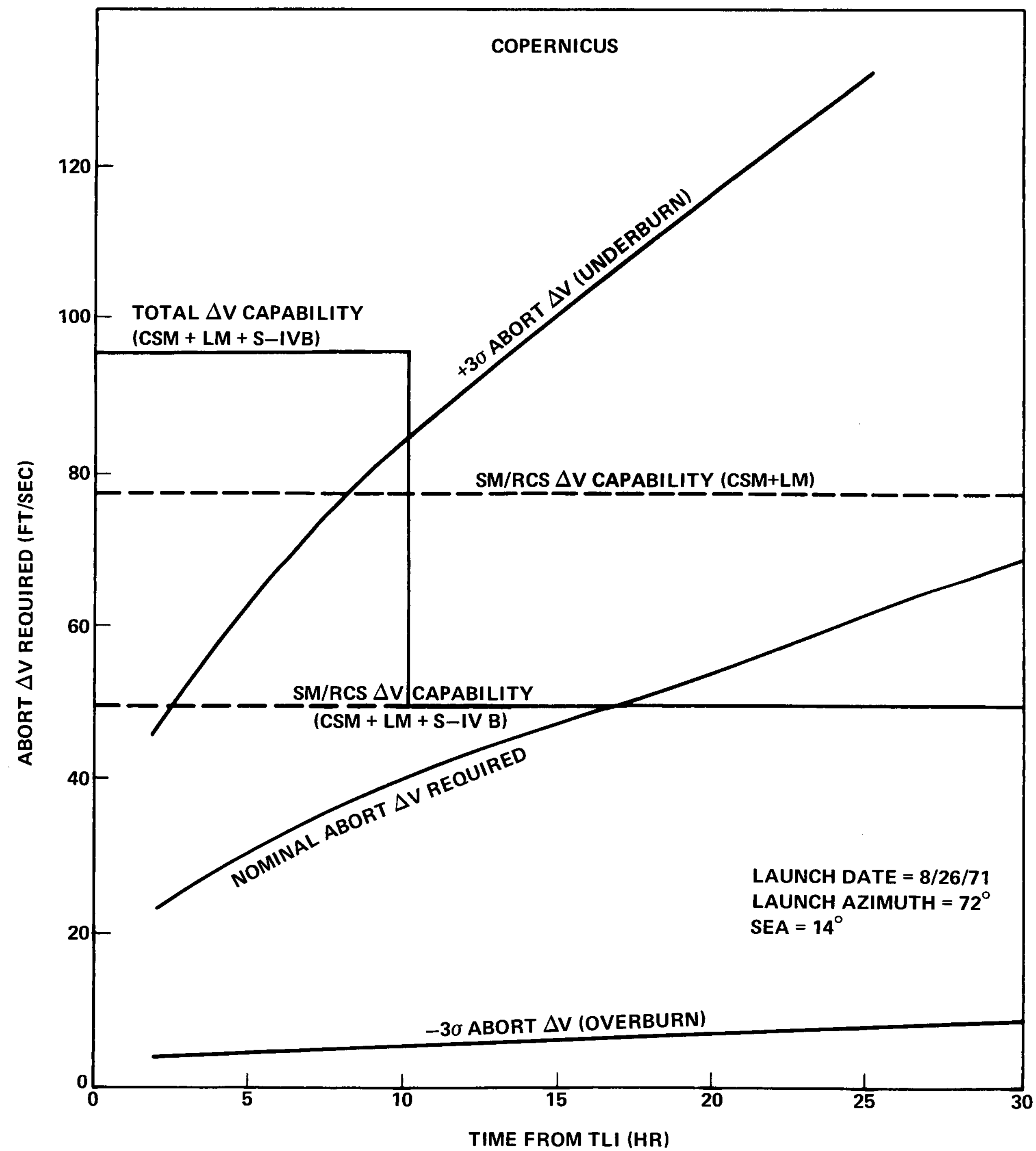


FIGURE 7 - 3σ ABORT ΔV REQUIRED FOR DISPERSED TLI.

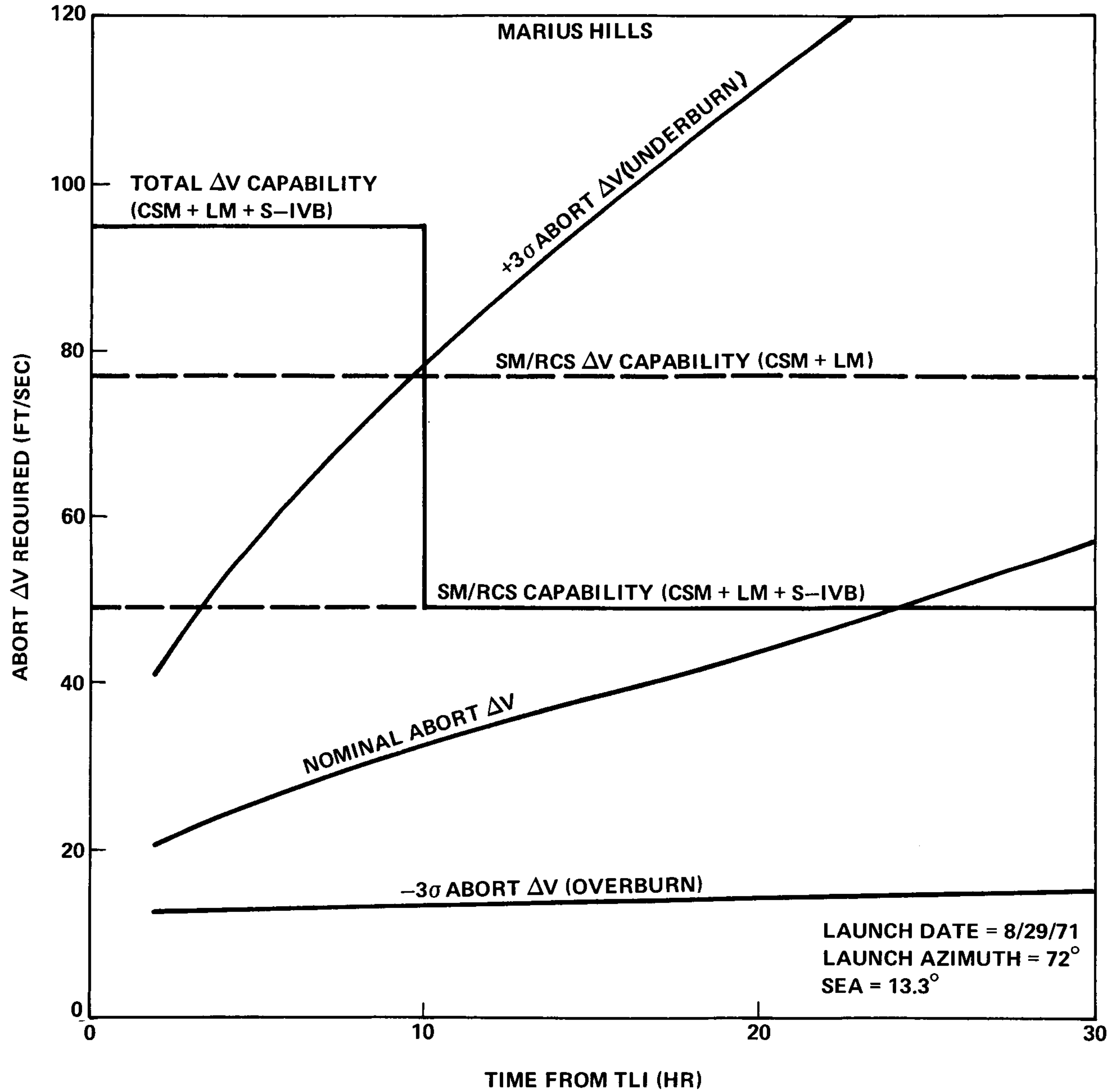


FIGURE 8 - 3σ ABORT ΔV REQUIRED FOR DISPERSED TLI

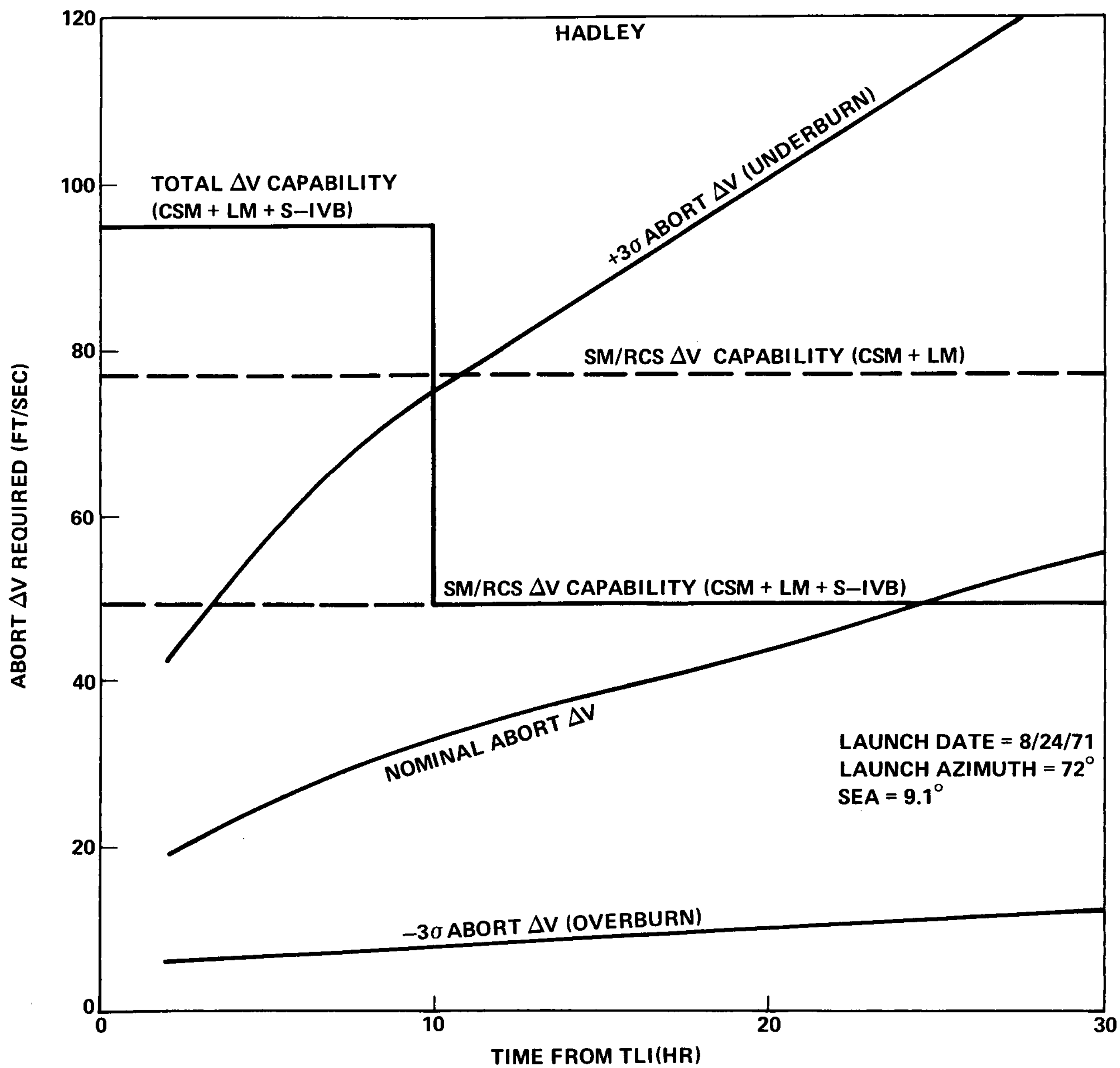


FIGURE 9 - 3σ ABORT ΔV REQUIRED FOR DISPERSED TLI

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